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Emergence of field-based underwater video for understanding the ecology of freshwater fishes and crustaceans in Australia

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Underwater video is increasingly being used to record and research aquatic fauna in their natural environment, and is emerging alongside Dual Frequency Identification Sonar (DIDSON) as a powerful tool in Australian freshwater ecology. We review current progress with field-based applications of underwater video in studying Australian freshwater fish and crustacean ecology. Drawing upon searches of online literature databases and our expert knowledge, we located 11 relevant publications: five set in the Murray-Darling Basin, three in the Eastern Province, two in the Northern Province and a single study in the Pilbara Province. In total, 10 studies reported using video for fish ecology, while three studies included crustaceans. Across the 11 publications, eight examined threatened species, while the remaining studies developed video techniques for surveying species richness in remote or difficult to access habitats. Habitat-use was also a dominant theme (seven studies). Seven of the eight studies that centred on threatened species focused on at least one percichthyid species in either the Murray-Darling Basin or the Eastern Province. Miniaturisation in equipment and increases in compact battery capacity seem to have driven a shift from above-water battery supplies and data storage to small, inexpensive and mobile underwater cameras. We foresee wider use of video in freshwater ecology primarily in the study of animal behaviour and also to improve species detection in field surveys. There is scope for testing novel techniques such as animal-borne video and unmanned underwater vehicles and making use of video in citizen science initiatives.

KEYWORDS: freshwater ecosystems, review, visual survey methods, aquatic fauna, animal behaviour, bait

INTRODUCTION

Underwater video, operated either manually or remotely, has been readily adopted in marine habitats spanning complex shallow reef biomes (e.g. Harvey *et al.* 2007; Holmes *et al.* 2013) to deep waters (e.g. Priede & Merrett 1996). Although less prevalent, video has also been used to research freshwater fauna in both laboratory (e.g. Lamprecht & Rebhan 1997) and field settings (e.g. Hinch & Collins 1991; Weyl *et al.* 2013). Such video applications have enhanced our understanding of the behaviour and physiology of Australian freshwater taxa, particularly with regard to captive individuals in laboratory settings (e.g. Richards & Bull 1990; Brown 2001; Crossland 2001; Karplus *et al.* 2003; Lowry *et al.* 2005; Wilson 2005; Patullo *et al.* 2007; Svensson *et al.* 2012). Areas of study have included turtle diving experiments (Priest & Franklin 2002; Clark *et al.* 2009), feeding, swimming and reproductive behaviour of the platypus, *Ornithorhynchus anatinus* Blumenbach, 1800 (Hawkins & Fanning 1992; Evans *et al.* 1994; Manger & Pettigrew 1995; Fish *et al.* 1997, 2001; Hawkins 1998; Holland & Jackson 2002; Hawkins & Battaglia 2009), and interactions involving amphibians including the alien cane toad, *Rhinella marina* (Linnaeus 1758) and its tadpole phase (Crossland 2001; Squires *et al.* 2008; Hamer *et al.* 2011; see also Shine 2014 and references within).

Field applications of video in Australian freshwaters have involved both above-water and underwater filming, such as the behavioural studies of waterbirds (e.g.

Dorfman *et al.* 2001; Murray & Shaw 2009; Winning & Murray 1997), crocodiles (Fig. 1e; Doody *et al.* 2007; Steer & Doody 2009; Somaweera & Shine 2011; Somaweera *et al.* 2011) and frogs (Byrne & Roberts 2004). In recent years, however, underwater video studies have been increasingly common. These studies have focussed on both fishes and crayfishes, and have often targeted clear-water systems (e.g. Butler & Rowland 2009), although some turbid-water examples exist (e.g. Fulton *et al.* 2012). Rapid advances in digital camera technology and affordability have likely driven this expansion.

While video has progressed our ecological knowledge, we believe the full potential of this technique is yet to be realised. Video is likely to be most helpful in understanding the ecology of speciose groups of large-bodied fauna, such as freshwater fishes, crayfish and large-bodied palaemonids (prawns of genus *Macrobrachium*) (Short 2004; Crandall & Buhay 2008; Humphries & Walker 2013) in difficult to access aquatic habitats. Here we aim to: i) review field applications of underwater video in studying freshwater fishes and crustaceans in Australia, ii) draw upon the collective experiences of researchers to identify advantages and disadvantages of video-based methods, and iii) outline future avenues for video to provide fundamental insights into freshwater ecology, particularly in an Australian context.

Field applications in Australia

Literature searches were conducted in three online databases (Web of Science, Scopus, National Library of Australia (NLA)) to identify relevant primary and grey literature. A single composite search term was used to identify literature that employed video or camera-based systems within Australian freshwater ecosystems: (video OR camera OR film OR visual) AND (freshwater OR aquatic OR river OR lake OR billabong) AND Austral*). The Web of Science search was restricted to 'Topic' and articles in English. Likewise, the search in Scopus was restricted to article "Title, Abstract and Key Words". The search in the NLA database was open to all fields (title, subject, author, publisher, series, ISBN/ISSN/ISMN, occupation), but restricted to books, newspapers, journals and manuscripts. Searches were not restricted to specific time periods, for example the Web of Science database searched from 1945–2014. Searches were performed in all three databases on 17 June 2014, and literature examined for relevant articles that examined aquatic fauna using camera systems in the field. Each article was evaluated based on its title and excluded if clearly not relevant (e.g. not on Australian ecosystems or not of biological or ecological context). Abstracts were examined for relevant papers (i.e. studies in Australian freshwater ecosystems with a biological context). Articles that did not identify the application of video systems were excluded.

Searches returned an initial total of 170, 190 and 209 articles from Web of Science, Scopus, and the National Library of Australia (NLA) databases, respectively. Further reading of these revealed six relevant journal publications identified in Web of Science, and no additional relevant literature was discovered via Scopus nor the NLA. A survey of Australian freshwater fish researchers (our authorship team) identified five additional publications. These publications included a recently accepted paper on the *Marine and Freshwater Research* website, an honours thesis, a report chapter and two government reports. The earliest of all these relevant publications was published in 2006.

Publications describing field-based applications of video were then coded according to five attributes: a) the freshwater fish biogeographic province (according to Unmack 2013) where the study was undertaken, b) focal taxa (fish, crustacean, other) and whether they were conservation listed species (Federally; and if not State listing was checked), c) primary study aims relevant to video application, d) type of camera equipment, and e) camera submergence (above water only, underwater only, both above and below water cameras). If details were ambiguous, we directly corresponded with the lead author to obtain the relevant information.

Location and focus of studies

Each study was set within a single bioregion; five were based in the Murray-Darling Basin (see Figure 1a, d), three in the Eastern Province, two in the Northern Province (see Figure 1b) and a single study in the Pilbara Province (Table 1). All studies except one reported filming fishes (e.g. Figure 1c), and three studies examined crustaceans (Figure 1d) (Table 1). Eight studies were oriented towards threatened species and the remaining three were focussed on developing video survey techniques for estimating species richness in remote or difficult to access habitats (Table 1). Seven of the eight studies that explored threatened species focussed on at least one percichthyid in either the Murray-Darling Basin or the Eastern Province (Table 1).

Habitat-use was a common theme, with seven studies exploring patterns of habitat occupation through time and/or space (including foraging, Table 1). These studies had a variety of aims (Table 1): four investigated reproduction, by filming spawning sites and/or parental care (Butler & Rowland 2009; Tonkin *et al.* 2009, 2010; Butler *et al.* 2014); two investigated depth occupation by fishes (Cousins 2011; Ebner & Morgan 2013); and one examined use of artificial habitat (Lintermans *et al.* 2010). Two publications reported using video techniques in concert with radio-tracking to determine habitat-use (Butler & Rowland 2009; Lintermans *et al.* 2010).

Examining the efficacy of survey methods was another key objective. Three studies compared video to other survey techniques (Fulton *et al.* 2012; Ebner *et al.* 2014) and one of these and an additional study compared baited and un-baited cameras (Ebner & Morgan 2013; Cousins 2011). Three studies compared estimates of species richness, principally of fish assemblages but also crustaceans (crayfish and palaemonids) and turtles (Cousins 2011; Ebner & Morgan 2013; Ebner *et al.* 2014). Additionally, Fulton *et al.* (2012) compared the efficacy of video, manual snorkel surveys and capture-based techniques for estimating the density and abundance of a crayfish species. While some video studies of fishes also observed turtles, mammals or birds, this was not necessarily part of their explicit aims (e.g. Butler & Rowland 2009; Lintermans *et al.* 2010).

A number of studies investigated video post-processing efficiencies (Ebner *et al.* 2009; Lintermans *et al.* 2010; Cousins 2011; Ebner & Morgan 2013). These

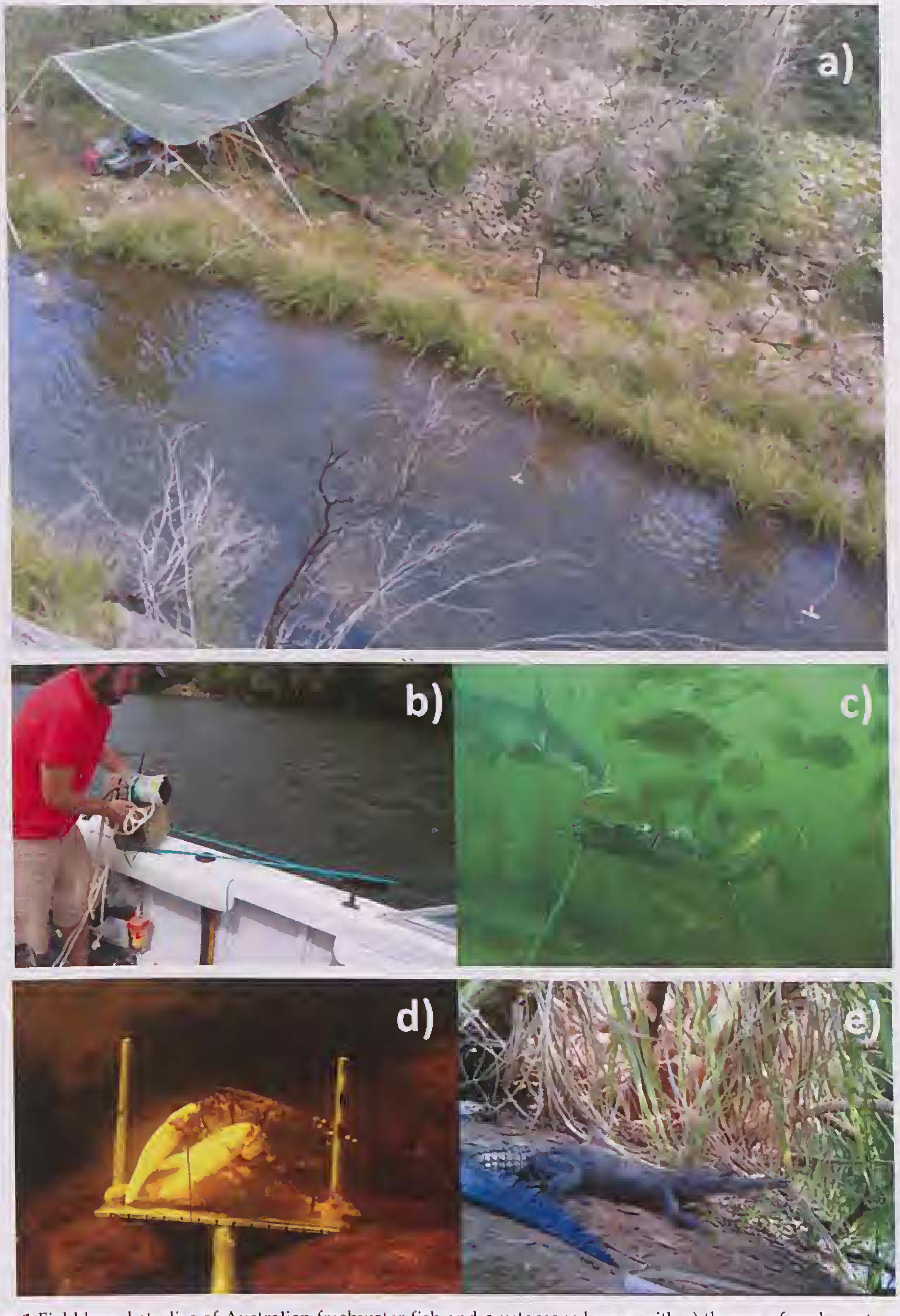

Figure 1 Field based studies of Australian freshwater fish and crustaceans began with a) the use of underwater cameras tethered to shore-based video cassette recorders and multiplexor units powered by a large battery supply (under tarpaulin), and has more recently expanded to include use of self-contained camera systems for b) deployment of baited camera, c) surveying fish assemblages, and d) counting crayfish; whereas, e) above water cameras have generally been used to study the behaviour of semi-aquatic fauna including freshwater crocodiles.

Table 1 Summary of field-based video studies of freshwater fishes and crustaceans in Australia to date. Biogeographic province was based on Unmack (2013) and conservation status was based on EPBC listing else state-level listing if not federally listed.

Study	Biogeographic province	Focal species	Conservation status	Focal taxa	Study aims	Camera equipment	Artificial lighting	Camera location
Broadhurst *et al.* 2006	Murray-Darling	*Maccullochella macquariensis*	Endangered	Fishes	Threatened species; behaviour; species reintroduction	Bankside VCR & Multiplexor & LCD screen (Analogue)	No	Above and below water
Butler & Rowland 2009	Eastern	*Maccullochella ikei*	Endangered	Fishes	Threatened species; behaviour; reproduction/ spawning habitat-use; overall habitat-use	Bankside VCR & Multiplexor & LCD screen (Analogue)	Yes	Below water
Ebner *et al.* 2009	Murray-Darling	*Macquaria australasica, Gadopsis bispinosus*	Endangered (*M. australasica*), *G. bispinosus* vulnerable in ACT	Fishes, crustaceans	Threatened species; behaviour; diel activity (including nocturnal)	Bankside VCR & Multiplexor & LCD screen (Analogue)	Yes	Below water
Tonkin *et al.* 2009	Murray-Darling	*Macquaria australasica*	Endangered	Fishes	Threatened species; behaviour	Bankside Computer & monitor (Digital)	No	Below water
Tonkin *et al.* 2010	Murray-Darling	*Macquaria australasica*	Endangered	Fishes	Threatened species; behaviour; reproduction spawning habitat-use; overall habitat-use	Bankside Computer & monitor (Digital)	No	Below water
Lintermans *et al.* 2010	Murray-Darling	*Macquaria australasica*	Endangered	Fishes, mammals, birds, crustaceans	Threatened species; behaviour; water resource management; artificial habitat-use; overall habitat-use	Bankside personal video recorders (PVR) (Digital)	No	Below water
Cousins 2011	Northern	Fish assemblage level	N/A	Fishes	Depth-use; overall habitat-use; species richness; technique comparison	Submerged Handycam (Digital)	No	Below water
Fulton *et al.* 2012	Murray-Darling	*Euastacus armatus*	Vulnerable (ACT) Vulnerable (NSW)	Crustaceans	Threatened species; behaviour; abundance assessment; technique comparison	Submerged Handycam (Digital)	No	Below water
Ebner & Morgan 2013	Pilbara	Fish assemblage level	N/A	Fishes	Depth-use; overall habitat-use; species richness; technique comparison	Submerged Handycam (Digital)	No	Below water
Ebner *et al.* 2014	Northern	Freshwater fauna	N/A	Fishes, reptiles, crustaceans	Species richness; technique comparison	Submerged Handycam (Digital)	No	Below water
Butler *et al.* 2014	Eastern	*Maccullochella ikei*	Endangered	Fishes	Threatened species; behaviour	Boat-mounted VCR & Multiplexor & LCD screen (Analogue)	Yes	Below water

included investigations of sub-sampling strategies relating to the amount of video processed, and in some cases the speed at which video could be manually processed to extract certain types of data.

A diverse spread of other topics was encompassed within this underwater video literature, including: elements of threatened species reintroduction (Broadhurst *et al.* 2006), angler effects on a threatened species (Butler & Rowland 2009), diel activity of crustaceans and threatened fishes (Ebner *et al.* 2009).

Video equipment

Three main types of equipment configurations were used in the studies we reviewed: a) bank-mounted video cassette recorder and tethered monochrome cameras, b) underwater digital cameras with tethered data storage units, and c) portable digital cameras with self-contained small rechargeable lithium batteries. Some of the first video-based studies used monochrome cameras (suited to low light conditions) tethered to bank-side (Broadhurst *et al.* 2006; Butler *et al.* 2009; Ebner *et al.* 2009) (Figure 1a) or boat-mounted (Butler *et al.* 2014) video cassette recorders (analogue) equipped with LCD screens or connected to laptop computers and powered by large batteries (traditional or gel cell lead acid batteries). These studies often used multiplexors to divide recorded frames from multiple cameras, and mostly relied on underwater filming. Broadhurst *et al.* (2006) was an exception in using both above and below water cameras. Artificial lighting was used in the studies of Butler & Rowland (2009) and Ebner *et al.* (2009).

The second type of video equipment was used in a single study involving underwater digital cameras with tethered data storage units and large batteries positioned on shore (Lintermans *et al.* 2010). This involved programmed personal video recorders (PVRs) that facilitated long term surveillance (days to weeks) without requiring manual intervention to change video cassettes. However, periodic downloading of video data was undertaken to minimise the risk of losing data. No artificial lighting was used.

More recently, the third type of equipment in the form of portable digital cameras with self-contained small lithium batteries has been adopted, which removes the need for onshore tethering to a power supply or recording device, but this can limit the filming duration (typically < 3 hrs). To date these applications have been confined to underwater day time filming in colour in the absence of artificial lighting (e.g. Cousins 2011; Fulton *et al.* 2012).

ADVANTAGES, DISADVANTAGES & CHALLENGES

Advantages

There are a number of advantages with using underwater video-based research to monitor freshwater fauna. It may represent the only viable or safe technique for answering particular types of research questions in certain environmental settings (e.g. Ebner & Morgan 2013; Ebner *et al.* 2014). For instance, video surveillance provides researchers with unparalleled opportunities to observe and measure behaviour (e.g. aggressive interactions, spawning activity and feeding mechanisms) otherwise unmeasurable by conventional survey techniques. Furthermore, video provides opportunity for long-term monitoring of behaviour where a human observer would become fatigued or would be in danger, as in many crocodile-inhabited tropical systems, or where the presence of researchers represents an unacceptable intrusion on aquatic community behaviour (e.g. Butler & Rowland 2009; Ebner *et al.* 2009, 2014). Similarly, underwater cameras may be useful for studying ecology in wetlands where access is difficult or is highly restricted, such as on military bases or airports. Cameras also permit observation in areas too deep (Cousins 2011) or fast-flowing for alternative sampling equipment, or in areas too shallow or complex for diver access (notwithstanding logistical issues). Video applications may also be highly desirable for discrete studies in environmentally sensitive areas. Examples include where humans demand a high standard of water quality (e.g. drinking water supply catchments, small springs) or where aesthetics and social considerations are paramount (e.g. urban parks, certain tourist viewpoints, national parks).

The non-destructive aspect of visual surveys, including video, is also ideal for studying rare or threatened species that are stressed, harmed or killed by capture-based methods and associated handling. For instance, amongst Australian freshwater fishes, clupeids, retropinnids and certain atherinids are sensitive to net abrasion, and electrofishing of *Maccullochella* and certain gudgeons (e.g. *Eleotris fusca*) requires special care. Moreover, even for species for which capture and handling is non-lethal or not obviously harmful, there is an ethical consideration around the trade-off between increasing data collection and increasing system disturbance. This consideration is perhaps most obvious in small systems where researcher disturbance modifies benthic habitat, temporarily impacts water clarity and may impact sensitive riparian vegetation.

Video also provides a record that can be reassessed in the future. With appropriate provisions for storage and future video file compatibility, footage can be reanalysed in the pursuit of new lines of enquiry, enabling virtual field trips back in time. Data extracted from the video can be checked or modified, perhaps with more advanced analytical techniques. Considering the cost of field trips to remote locations, being able to mine film archives of permanent records of underwater environments and faunal communities seems likely to benefit ecologists that specialise in particular fauna groups, even if those species were not initially targeted. Video replay also enables the slowing of frame rates to enable measurement of behaviour that would otherwise be impossible for the human eye to resolve (e.g. Breder & Edgerton 1942).

Video clearly has a role to play in public communication. Mainstream documentaries that engage and educate the public about the natural world are immensely popular. In this regard, researchers have much to gain from using their underwater films to entertain and educate non-researchers about new discoveries. This can be done via freely available public online video resources (e.g. YouTube, Vimeo). Arguably, few other survey techniques used to study freshwater fish and crustaceans have this capability of reaching broad audiences and large numbers of people around the globe. The potential to showcase our unique Australian freshwater fauna is large. For example, during an 18 month period, over 3,000 people viewed YouTube footage of Murray crayfish collected by Fulton *et al.* (2012).

Disadvantages

A primary limitation of visual survey techniques involving video is their reliance on clear water, and therefore, poor function in turbid waters (Broadhurst *et al.* 2006). This means that video has limited applicability in many of the large lowland rivers of northern and inland Australia, such as Cooper Creek and the Darling River (e.g. Fellows *et al.* 2009), or tannin-stained swamps and wetlands. Systems exposed to severe or common sediment disturbance may also render themselves inappropriate for video research. For instance, a major bushfire in the Australian Capital Territory led to sedimentation of local streams which thwarted a short-term video-based research project (Ebner *et al.* 2009) and stifled a separate research project years later when re-suspension of sediment following a major rainfall event coincided with a translocation experiment (Broadhurst *et al.* 2006). Furthermore, our collective experiences include a number of unpublished field exercises where video was severely compromised by temporarily elevated turbidity associated with short-term high rainfall and sediment run-off events. However, in some cases it may be possible to use video in turbid waters, such as the study by Fulton *et al.* (2012) which was able to exploit the attraction of Murray River crayfish to bait to capture their presence in the Cotter River. Dual Frequency Identification Sonar (DIDSON) (Tušer *et al.* 2014) provides a promising alternative to video-based techniques in turbid environments.

Another disadvantage is light limitation. The dependence of cameras on light means that studies are typically confined to daylight hours. This means that species particularly active at night, such as some freshwater catfishes, may be underestimated by video. Two studies have used video at night: a pilot study monitoring the diel activity of threatened fishes in the Cotter River based on infrared lighting (i.e. Ebner *et al.* 2009) and a study recording the diel behaviour of nesting Eastern freshwater cod (*Maccullochella ikei* Rowland 1986) based on white lighting (Butler & Rowland 2009). Whilst infrared lighting is likely to be important for non-obtrusive behavioural studies, the use of conventional lighting and baited cameras may be a viable option for detecting the full breadth of nocturnal fauna diversity; and in fact light may serve as an additional attractant for certain taxa.

Hardware malfunction or poor performance of cameras can also be an issue. Electrical errors can occur when collecting and storing video, batteries can overheat or degenerate, and memory media can become corrupted (Lintermans *et al.* 2010; Ebner *et al.* 2014). Camera performance declines when lenses are fogged or when glare or reflection is intense. Fogging can be countered with desiccant bags and glare and reflection can be partially dealt with by carefully positioning cameras relative to the position of the sun and by using lens filters.

Another important limitation of underwater video is reduced confidence in taxonomic identification. This is especially relevant when viewing small individuals, those that are distant from the lens, or for species that do not have easily distinguishable morphological or behavioural traits. For example, Lowry *et al.* (2011) noted difficulty in discerning fish species with similar appearance (typically juveniles) or those that move rapidly past the camera. These factors are unlikely to be an issue for Australian crayfish because individuals move slowly and species richness is usually low within any catchment or site. However, the identification of small-bodied species, including the early life history phases of many fishes, is likely to be a real difficulty at sites with high species richness and multiple small-bodied species. This is probably more of an issue in the tropics, but may also be an issue at specific locations in temperate Australia where sympatry of congeneric species occurs [e.g., where multiple *Nannoperca* spp. cohabit in south Western Australia (Morgan *et al.* 2013) and south eastern Australia (Saddlier *et al.* 2013), and where galaxiid species richness is high (Adams *et al.* 2014)]. However, in some fish assemblages, such as where sicydiine gobies are a feature of short-steep-coastal streams in the Wet Tropics, there are times of year when heightened coloration aids the video-based demarcation of sympatric congeneric species (and sexes) during extended courtship periods (Ebner & Donaldson, pers. obs.).

Methodological challenges

An important issue in the emerging field of freshwater video research is differential detection associated with different types of bait (including no bait), different baiting methods, and different environmental conditions. This variation in detection capability reduces our ability to compare the findings within a study through time and space, to compare between different studies and to conduct meta-analyses.

Different baits and baiting methods have arisen because researchers target different species or taxa (e.g. fish versus crayfish), or because sometimes they target single species and at other times the assemblage (e.g. threatened species versus whole fish community). We currently know little about the ability of different baits to attract freshwater taxa, but we know that some species prefer one bait type over another and that the freshness of bait is likely an important factor (Løkkeborg & Johanessen 1992; Dorman *et al.* 2012). We also know the capacity of bait to attract species will differ depending on whether or not a species primarily hunts visually or by olfaction (Bassett & Montgomery 2011).

One approach to control for detection is to standardise bait type and baiting method. Considerable efforts have been made to find a suitable standard bait. For example, many of the authors of this paper have investigated the use of defrosted pilchards, *Sardinops sagax* (Jenyns 1842) – a bait that is widespread in marine video studies (e.g. Harvey *et al.* 2007; Holmes *et al.* 2013). Unfortunately, field trials by the authors of the current paper have revealed practical considerations that need to be resolved for this bait type to be successful. Issues include the limited refrigerated storage space in cars, boats, helicopters or on-person, and the poor longevity of bait during long and remote field trips (greater than a week). We encourage more pilot studies that investigate optimal baits for species or assemblages.

An alternative to standardising bait is to use un-baited cameras. There is currently much contention about whether or not to bait. A small amount of defrosted bait or canned food may draw certain rarely-detected species to the camera thus saving post-processing time and effort, but deploying more replicates of un-baited cameras requires less hassles with field equipment (e.g. bait bags and associated mounting structures) and bait storage requirements, improving portability and accessibility in remote areas. Comparisons of baited and un-baited cameras in Australian freshwater systems have revealed subtle differences in species richness estimates derived by either technique (Cousins 2011; Ebner & Morgan 2013). Preliminary indications are that camera placement with respect to depth and microhabitat may actually be more influential for estimating species richness and assemblage composition in freshwater systems than baiting or not baiting cameras (Cousins 2011; Ebner & Morgan 2013; Ebner *et al.* 2014). Unfortunately, overcoming some of these issues is not as straightforward as increasing the numbers of camera placements. Pseudo-replication and double-counting of individuals come into consideration. In the case of baited cameras, how bait type affects species detection and species selectivity remains to be investigated in freshwater systems. This extends to understanding how fish assemblages behave in relation to the activity of a subset of species that is stimulated by introducing a bait.

An alternative and more sophisticated approach is to use mathematical models such as Bayesian hierarchical models (Royle & Dorazio 2008) that estimate and correct for variation in detection (e.g. Beesley *et al.* 2014). These models use variation in data among replicate cameras to estimate detection at the site level, and then correct estimates of abundance (or occupancy) for differences in detection among sites. Picture frames from a single camera may also be treated as replicates, allowing variation in detection through time to be modelled (see Coggins *et al.* 2014). This will allow data that have been collected from cameras with different deployment times to be legitimately compared. The models are fairly robust but inference can be further strengthened by collecting information on the variables likely to affect detection. We recommend that researchers collect information relating to variables that describe bait-attractiveness and effectiveness (e.g. bait type, bait size, water depth or volume, and flow velocity), and those related to camera efficiency (camera type, water turbidity, light levels, camera depth in water, surrounding habitat etc.).

FUTURE APPLICATIONS

Most published field-based applications of video research of Australian freshwater fishes and crustaceans have centred on threatened species (particularly percichthyids). In many cases, these studies have employed video to understand behaviour and habitat use. The discovery that *M. ikei* parentally guards its egg and larvae (Butler & Rowland 2009) is a clear demonstration of the type of ecological information that can be obtained by underwater video that is unattainable by conventional methods. From an applied perspective, an application of underwater video surveillance to test *Macquaria australasica* Cuvier, 1830 association with particular artificial habitat (Lintermans *et al.* 2010) was invaluable in attempting a level of sustainability for a major dam construction project in the Australian Capital Territory. Both of these examples used video to complement applications of radio-telemetry and deployed multiple cameras over multiple seasons or years (Butler & Rowland 2009; Lintermans *et al.* 2010). Together these studies indicate the benefits of video for threatened species research, alongside the tremendous scope for using highlights from research footage to promote public interest and increase understanding of the plight of threatened species.

There is considerable scope for using video to evaluate the effectiveness of conventional techniques. In particular, video can provide a means of exploring species-specific behavioural responses to different survey methods (e.g. Grant *et al.* 2004), or provide checks on our understanding of the relative abundance of species, extremes in their distribution and abundance, and cryptic habitat use. To date, most studies in Australia have used underwater cameras in a field context to compare with and/or complement conventional sampling methods (e.g. netting, electrofishing), or applied video directly to assess the abundance of a key freshwater species, or investigate patterns of species richness. These studies have revealed that camera-based techniques can be superior to conventional sampling techniques, particularly for hard to catch species (e.g. Ebner & Morgan 2013); but that manual survey methods (e.g. trained human observers working on snorkel) could provide an equally effective or superior technique (Fulton *et al.* 2012; Ebner *et al.* 2014). Where video has a similar efficacy to traditional gear, the increasing affordability and image quality of portable cameras (e.g. GoPro®) is making the former an increasingly attractive option, particularly where equipment and training costs are prohibitive. For instance, boat electrofishing is a specialised and expensive outlay for short-term student projects. The complementary role of video as an additional sampling method, and a means of assessing the effectiveness of conventional techniques (e.g. Grant *et al.* 2004), means that video should be considered even when equipment and expertise costs are not a limiting factor. Indeed, in many cases, video may be the only viable option for exploring the ecology of freshwater species in the wild where human access is compromised or observer safety is at risk.

The general consensus amongst the authorship group was that underwater video has a major role to play in developing an understanding of the behaviour of freshwater fishes and crustaceans in Australia. In part, this is because many commonly used sampling methods are capture-based and not well suited to behavioural observation. Telemetry methods (radio, acoustic, passive integrated transponder based techniques) provide a notable exception, but video has the capacity to garner different types of behavioural information (e.g. predation, predator avoidance, competitive interaction) because it acts at finer spatial and temporal scales and can be used to study non-tagged individuals and species.

For these reasons both telemetry and video can play complementary and synergistic roles (e.g. Butler & Rowland 2009; Cooke *et al.* 2001). From a practical perspective, video has a bright future in elucidating interactions between aquatic species and humans (e.g. fishways, anglers, habitat restoration). There is also major potential for overcoming biases or at least confirming the relevance of laboratory based studies of aquatic fauna by conducting field based underwater video.

While cameras have facilitated laboratory and microcosm studies of freshwater fauna in Australia for several decades (e.g. Sandeman 1985; Richards & Bull 1990; Manger & Pettigrew 1995), the field-based video study of freshwater fishes and crustaceans in Australian freshwater ecosystems has only arisen in the past decade. Initially, this included use of analogue video recorded on magnetic film and powered by large gel-cell batteries (Butler & Rowland 2009; Ebner *et al.* 2009), and then, in time, moved to more portable media such as handheld digital cameras (e.g. Fulton *et al.* 2012). The reduced cost and size of cameras is poised to enable much wider use and/or greater replication across habitat types, times and/or sites. In turn this is likely to provide significant improvements for researching fishes and crustaceans since the limited field of view of a single camera is highly restrictive. Critical thinking is required in deciding on camera deployment strategies according to tradeoffs with cost, the potential risk of observer effects and pseudo-replication. Mobile cameras including towed cameras, manned underwater vehicles (e.g. Jones 2009) and animal-borne video (e.g. Heithaus *et al.* 2001) provide alternatives. Additionally, film has the capacity to facilitate communication of science and information about the natural world to the public. More than that, through evolving citizen science initiatives, such as crowd-sourcing, there is scope for involving people in data collection and processing phases of underwater video research. From a conservation perspective, this may just be the greatest opportunity for video-based ecology.

CONCLUSIONS

A small but steady number of video-based studies of Australian freshwater fish and crayfish has emerged during the past decade. These studies have included both temperate and tropical Australia. Encouragingly, other research is underway in provinces that have not previously been studied by video methods (e.g. Kimberley, Tasmania). There is much promise for video-based ecological investigations in upland lotic systems where clear water conditions often prevail and certain taxa attain their greatest species richness (e.g. spiny crayfish *Euastacus* spp., fishes of the Galaxiidae). To date, there have been no published applications from natural lentic systems in Australia despite promising research overseas (e.g. Mueller *et al.* 2006). There is clearly scope for the application of video in swamps and lakes with good visibility. There is also scope to use unmanned underwater vehicles (e.g. Jones 2009) and animal-borne video (e.g. Heithaus *et al.* 2001).

In the future we see video becoming a standard technique for surveying a broad diversity of freshwater fauna in clear water systems in Australia and elsewhere.

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